HEALTH EFFECTS OF INDOOR-AIR BENZENE IN ANCHORAGE RESIDENCES:

A STUDY OF INDOOR-AIR QUALITY IN HOUSES WITH ATTACHED GARAGES

PREPARED FOR
MUNICIPALITY OF ANCHORAGE

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Introduction

Benzene is a known carcinogen. It affects white blood cells; it causes leukemia and aplastic anemia. It may also affect the immune system which is dependent on white blood cells.[1]

It has been removed from all household products, but it is still present in gasoline. Alaskan gasoline is particularly high in benzene (>5%). Gasoline refined in Alaska has high concentrations of benzene and other the aromatic compounds as much as 50% aromatics by volume. Leaving the aromatics in the gasoline helps cars start in the cold, but it also puts high concentrations of benzene in both the ambient and indoor air. We already knew from previous work done in Alaska by Bernard Goldstein in Valdez[2] and the Anchorage Department of Health and Human Services in Anchorage[3] that people were exposed to high ambient levels of benzene in the winter, and that there were high indoor benzene concentrations in homes with attached garages if the garage was used to store gasoline or gasoline powered engines.

Benzene does not bioaccumulate in the body as dioxin or some pesticides do. But are its effects cumulative? Does a little dose of benzene everyday have the same effect as a large dose over less time? Benzene reduces CD4 cells in a dose-response manner at workplace concentrations less than 1 ppm (OSHA 8-hour exposure limit) in workers.[4] People who live in homes with high benzene concentrations may be exposed 24 hours a day, seven days a week. There have been no studies of health effects of such environmental exposure to benzene. This study was done to determine three things:

1. **What percentage of Anchorage homes with attached garages had high levels of indoor benzene?**
2. **Were the high levels of indoor benzene affecting the health of the residents?**
3. **Were residents more likely to develop asthma in homes with high levels of indoor benzene?**

Methods

The protocol for this study was submitted to the Institutional Review Board of the University of Alaska Anchorage. It was given an exempt status. It was also submitted to the Human Subjects Review Officer for EPA and was passed with minor revisions.

A pilot study done the previous year tested whether householders could successfully measure the levels of indoor air pollutants using passive vapor badges designed originally for industrial hygiene monitoring. The Municipal Air Quality Section had tested these passive badges in co-location studies with vacuum canisters. They were found to be accurate within EPA standards. The pilot study recruited 84 households who successfully measured indoor air pollutants receiving and returning the badges to us by mail. Householders were recruited from the property tax base which could identify houses with attached garages. Monetary incentives were offered and the methods were shown to be practical, less invasive, and less expensive then sending technicians into homes with vacuum canisters. We used the same methods that had been tested the previous year.

Recruitment

The study was done by mailing a recruitment letter to a random sample of homes from the Anchorage tax records. The tax records indicated that the house had an attached garage. A second criterion was that the house be owner-occupied. Although we knew that exposure to benzene in the home was the result of personal lifestyle choices, we did not want to incur any landlord/tenant conflicts. There were almost 10,000 homes in Anchorage municipality that met these criteria. The computer randomly selected 2000 of them. The file was cleaned by eliminating any houses that were owned by estates, churches, or companies. The resulting 1700 households were sent recruitment letter one (see appendix). To improve the recruitment process and give us more statistical power, we waited three weeks after the initial mailing and sent a second letter to those who had not responded to the first letter. In order to determine whether there might be a difference between those who would respond and those who did not want to respond, we sent a copy of the household survey with the second letter and asked people to please fill it out and return it even if they did not wish to participate in the study. When people returned the recruitment letter and stated that they did not want to participate, but gave us their telephone number, we called them and asked them if they would be willing to answer the household survey questions which were all written to maintain a high degree of anonymity for the householders. Most of them were willing to do so. Five households completed the indoor air measurements but did not answer the survey questions.

In the winter of 2007-2008 we investigated the indoor air in over five hundred homes with attached garages that were randomly selected from the tax records. Five hundred seventy one (571) households out of 1700 (34%) randomly selected households responded in our indoor air study. They were asked to complete a household survey and personal health surveys for each person in the home and to measure the benzene in the home for one week with passive vapor monitors. Surveys and unopened badge canisters were sent to all households that agreed to participate. There were specific instructions about how to open and display the badge. Every tenth household was sent two badges which they were told to display together for quality assurance. When study materials were returned, the badge numbers were recorded, the opening and closing times were recorded, and the surveys were entered into a database by an experienced data entry person. Badges were taken to the ASET laboratory as they accumulated.

Badges were extracted and analyzed for benzene, ethylbenzene, toluene, and xylenes (BETX) by a Varian 3800 gas chromatograph equipped with an 8400 auto injector. Quality assurance was done by using field blanks, laboratory blanks, and 10% duplicate samples. Field blanks and laboratory blanks were all below detection limits for BETX and duplicates were correlated at R=.99.

Results

The following table shows the results of the recruitment.

Table 1: Study disposition

Responses to recruitment	Frequency	Percent
Agreed to participate, completed surveys and monitoring	509	89.1
Agreed, completed monitoring, but did not complete surveys.	5	.9
Agreed, completed HH surveys, but did not complete monitoring	40	7.0
Refused to participate but completed HH survey	12	2.1
Badge was lost in lab	1	.2
Package was returned after deadline (May 1, 2008)	4	.7
Total	571	100.0

The four households who submitted the package after the May 1, 2008 deadline were eliminated from analyses as we were looking at indoor air quality during winter months. We did however analyze the badges of the late-comers and sent them the outcomes although they were not eligible for the incentive cash drawing. We looked at those who had completed indoor air monitoring and those that had not completed the monitoring to determine if there were any significant differences between the two households. It may also be significant that all of the non-monitored houses were single-family residences while nine of the monitored residences were multi-family dwellings.

There were two areas where the two groups differed significantly. They were in the location of the furnace and in the presence of condensation on the windows during the winter.

Table 2: Comparing Monitored versus Non-monitored Households

		Location of furnace or boiler				
		Inside garage	Crawl space	Basement	Other	Total
houses were monitored	No	27 (51%)	9 (17%)	12 (23%)	5 (9%)	53
	yes	362 (71%)	44 (9%)	59 (12%)	42 (8%)	507
Total		389	53	71	47	560

Pearson Chi-Square=11.0, df=3, p= .011

It appears that households where the furnace was located in the garage were more likely to follow-through with the indoor air monitoring. These households may have had a greater expectation of risk than households where the furnace was in other locations.

Table 3: Comparing monitored versus non-monitored houses regarding ventilation issues

		Moisture condensed on windows		
		Yes	No	Total
houses were monitored	No	29 (55%)	24 (45%)	53
	Yes	357 (71%)	147 (29%)	504
Total		386	171	557

Pearson Chi-Square=5.9, df=1, p=.016

The other areas that were examined were the age of the house, the zip code, the number of persons in the house, the size of the house, household income, smokers in the house, mold or mildew in the house, moldy odors in the house, how many vehicles were kept in the garage, how many engines were kept in the garage, and whether gasoline was kept in the garage or house. None of these areas showed any significant difference between those who monitored and those who did not.

Apparently people were more inclined to monitor if there were things not easily under their control that put them at risk for indoor air problems, but not more inclined to monitor for their own behavioral risk factors.

There are a total of 509 households for which we have monitoring and survey data done during the winter of 2008. Here are the descriptive statistics for the numerical data.

Table 4: Descriptive Statistics for continuous household variables

	N	Minimum	Maximum	Mean	Std. Deviation
Sq footage of house	496	1000	8000	2368.64	906.49
Number of residents per household	509	1	15	2.9	1.5
Number of children under 18	509	0	13	.8	1.3
# vehicles kept in garage	507	0	6	1.5	.7
# gas-powered engines kept in garage	505	0	10	1.6	1.5
Total # animals inside house	509	0	13	1.3	1.5
Total number of engines plus vehicles in garage	503	0	13	3.1	1.8

The annual income for the participants was higher than the average income for residents of Anchorage but the recruitment targeted only home owners with attached garages. The sampling was therefore not representative for lower income persons.

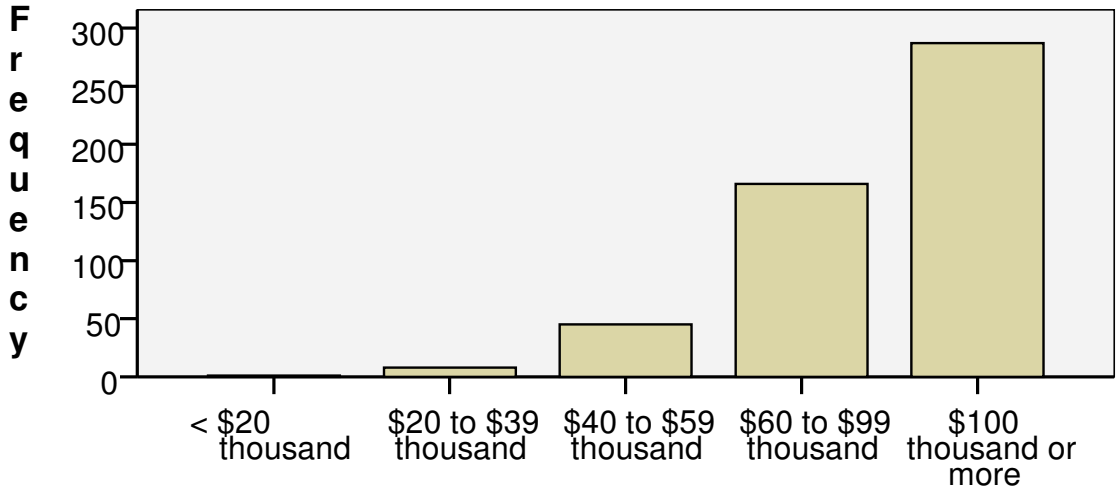


Figure1. Total Household income in the past 12 months

The majority of houses was heated with gas and had forced air heat. Because there were so few in our sample with other types of heat we were not able to do any analyses of heating systems other than the location of the unit.

Table 5: Primary heating system * Primary source of heating

		Primary source of heating		
		Natural gas	Electricity	Total
Primary type of heating system	Forced air	444	2	446
	Radiant hot water	49	2	51
	Comb. forced air/radiant hot water	9	0	9
Total		502	4	506

There are nine cases that have combined forced air and radiant hot water and these nine cases include an outlier with the highest benzene measurement (23 ppb higher than second highest value). If the nine cases are removed neither the type of heat nor the location of the furnace is significant as we see in the table above. If only the outlier is removed there is no significant difference between heating type and location of furnace or boiler, but with the outlier as part of a small group, the combination forced air and radiant heat with the furnace in the garage appears significant. You can see in this table where ANOVA shows a significance p=0.046, but the entire weight of that significance depends on one value. When that one value is removed the mean benzene for inside the garage with combined system becomes 4.8589 and the significance becomes p=.749.

Table 6: Location of furnace eliminating cases with combine forced air and radiant heat

Primary heating system	Location of furnace or boiler	Mean Benzene	N	Std. Deviation	Median	Maximum
Forced air	Inside garage	4.80	320	5.25	3.12	34.55
	Crawl space	3.68	42	4.40	1.54	17.39
	Basement	4.07	48	5.92	2.03	31.78
	Other	4.90	36	6.32	2.52	21.95
Radiant hot water	Inside garage	4.19	39	6.35	2.26	31.29
	Crawl space	4.80	1	.	4.80	4.80
	Basement	9.04	9	12.21	2.95	35.56
	Other	4.06	2	3.23	4.06	6.34
Total	Inside garage	4.73	359	5.37	3.02	34.55
	Crawl space	3.71	43	4.35	1.54	17.39
	Basement	4.85	57	7.35	2.10	35.56
	Other	4.85	38	6.17	2.52	21.95

Table 7: Report on location of heating system and mean benzene including all cases

Primary heating system	Location of furnace or boiler	Mean benzene	N	Std. Deviation	Median	Maximum
Forced air	Inside garage	4.80	320	5.25	3.12	34.55
	Crawl space	3.68	42	4.40	1.54	17.39
	Basement	4.07	48	5.92	2.03	31.78
	Other	4.90	36	6.32	2.52	21.95
Radiant hot water	Inside garage	4.19	39	6.35	2.26	31.29
	Crawl space	4.80	1	.	4.80	4.80
	Basement	9.04	9	12.21	2.95	35.56
	Other	4.07	2	3.23	4.06	6.34
Comb. forced air/radiant hot water	Inside garage	31.57	2	37.78	31.57	58.29
	Crawl space	.87	1	.	.87	.87
	Basement	7.09	2	8.09	7.09	12.81
	Other	2.12	4	2.56	1.33	5.84

Laboratory results

There were eighteen households whose badges were zero for all contaminants (benzene, toluene, ethylbenzene, and xylenes). There were a total of 54 households that had zero benzene but small amounts of other contaminants most commonly toluene.

Table 8: Descriptive Statistics Regarding BETX Analysis

		Benzene	Toluene	Ethylbenzene	Xylenes
N	Valid	509	509	509	509
Mean		4.74	12.80	1.36	5.83
Median		2.88	7.34	.83	3.01
Mode		.00	.00	.00	.00
Std. Deviation		6.06	18.45	1.76	8.36
Minimum		.00	.00	.00	.00
Maximum		58.29	179.17	13.74	77.26
Percentiles	25	1.19	3.03	.34	.00
	50	2.88	7.34	.83	3.01
	75	5.92	14.68	1.74	8.05

The following histograms show the distribution of benzene, toluene, ethylbenzene and xylenes in the households in this study.

Figure 2: Distribution of Benzene in Alaska homes with attached garages

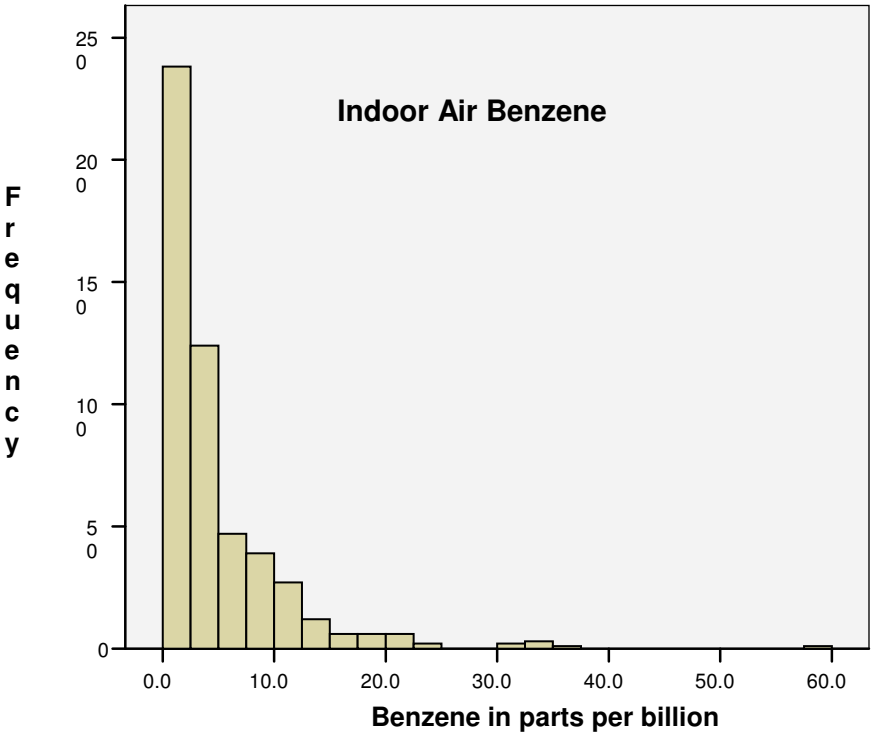


Figure 3: Distribution of Toluene in Alaska homes with attached garages

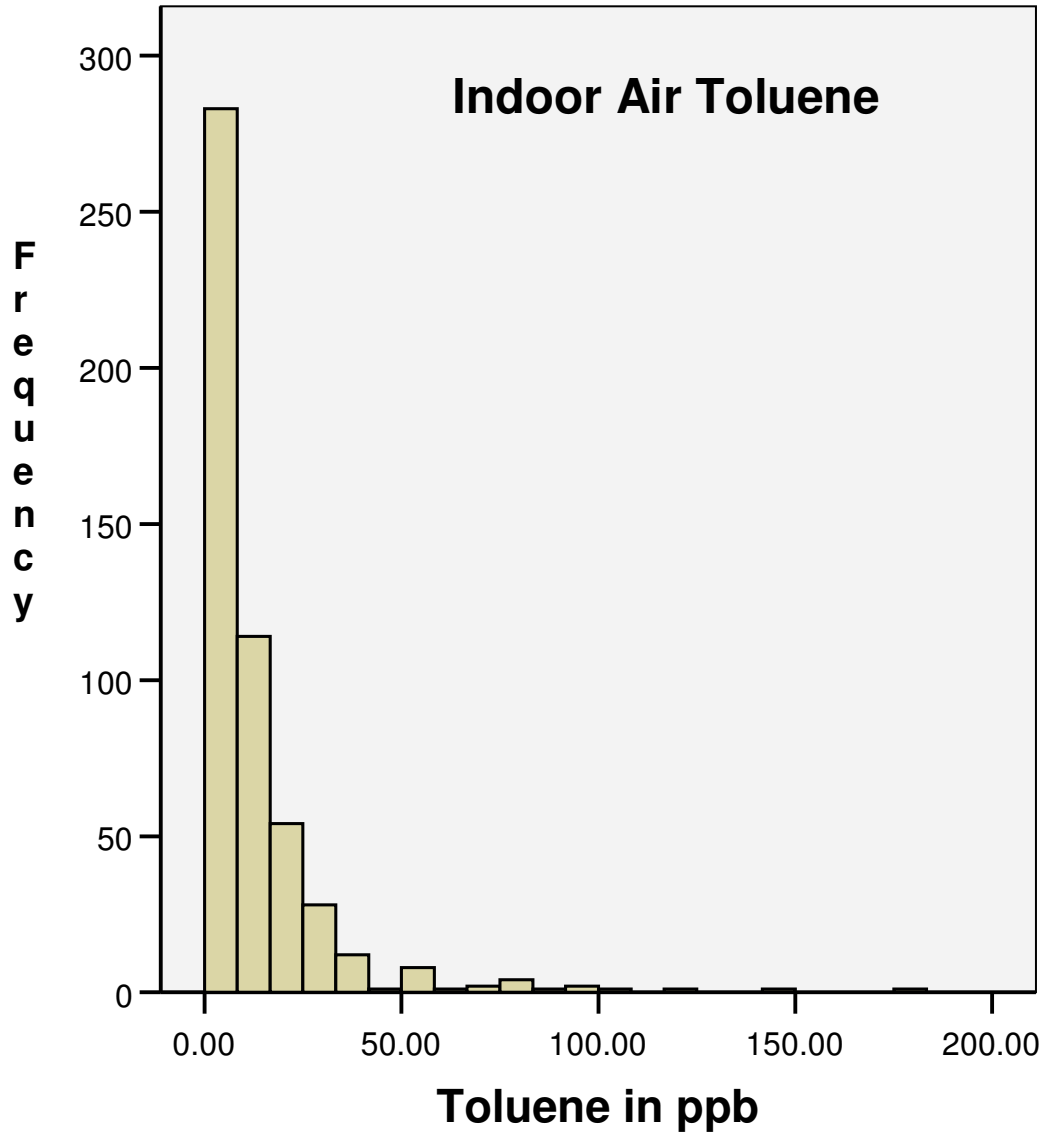


Figure 4 Distribution of Ethylbenzene in Alaska homes with attached garages

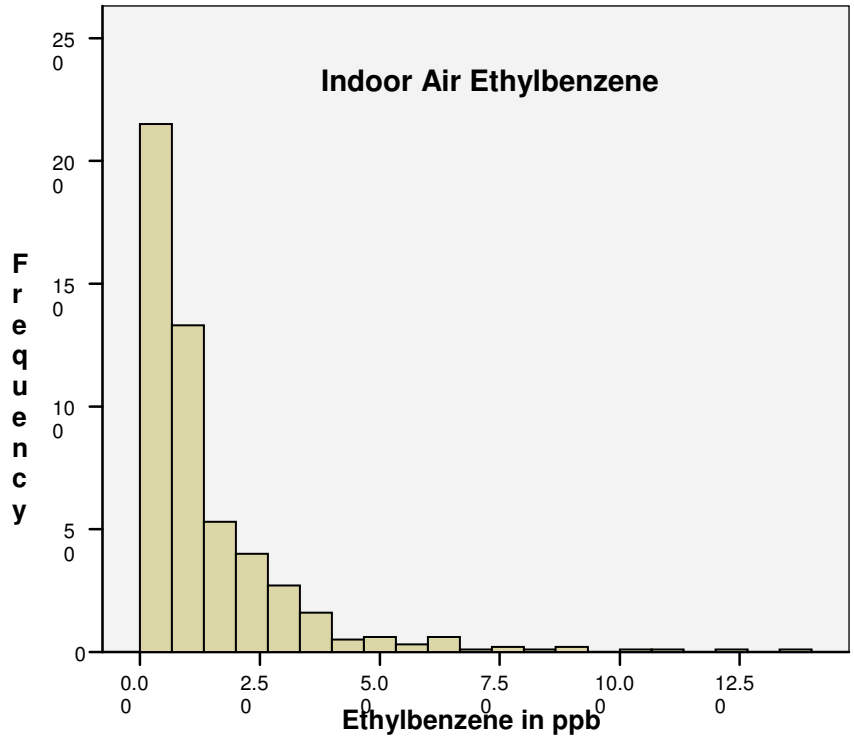
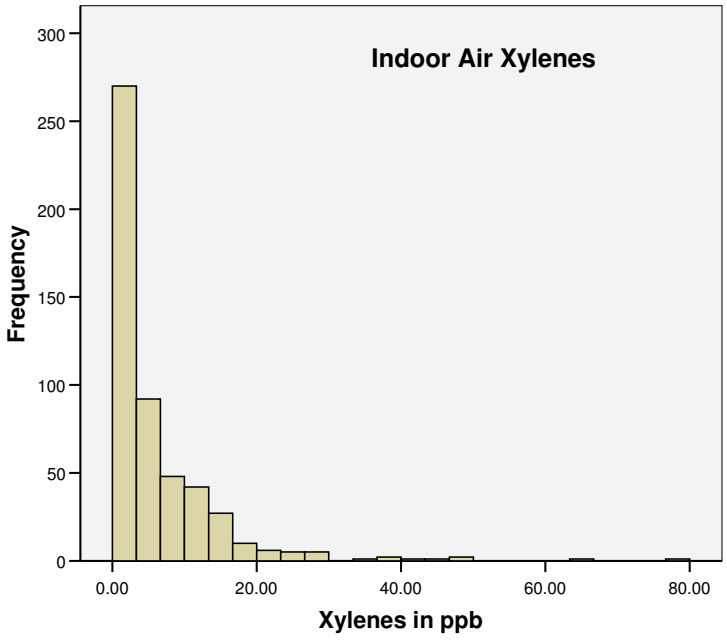


Figure 4: Distribution of xylenes in Alaska homes with attached garages



Work done previously by the Air Quality Section at the Municipality showed ambient air benzene was not a major contributor to indoor air benzene. We did not do any ambient air benzene measurements in this study. However, there were some differences between the mean benzene for houses in different zip codes. Zip code differences could be affected by the number of newer houses in the different zip codes. Newer houses were somewhat more likely to have high indoor benzene levels than older houses as we see in the following table. This relationship does reach borderline significance.

Table 9: Benzene greater than median vs. year of construction

	2000 or later	1980 to 1999	1960 to 1979	1959 or earlier	Total
Number of houses with more than median amount of benzene	50 (53%)	176 (51%)	22 (47%)	5 (23%)	253 (50%)
Total	95	344	47	22	508

Pearsons Chi-Square p=.066

However if you examine the data from the view of the mean indoor air benzene in the houses of different ages you find that the houses built between 1960 and 1979 have the highest mean benzene. An ANOVA table shows that this does not reach significance (p=.176). If you remove the highest value of indoor air benzene (58.3 ppb) as an outlier, the difference disappears.

Table 10: Year of construction with mean benzene (using all values of benzene)

Building first constructed	Mean Benzene	N	Std. Deviation	Median	Maximum
2000 or later	4.80	95	4.92	3.09	22.24
1980 to 1999	4.68	344	5.68	2.91	35.56
1960 to 1979	6.06	47	10.11	2.36	58.29
1959 or earlier	2.63	22	4.48	1.18	16.63
Total	4.74	508	6.06	2.83	58.29

ANOVA p=.176

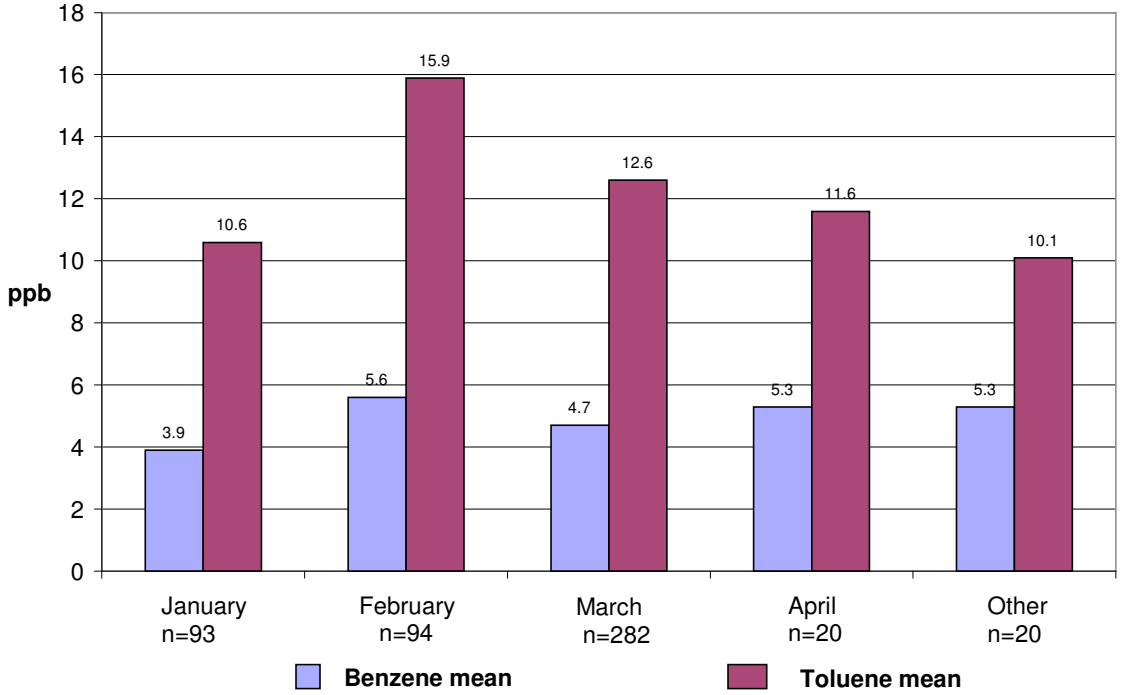
Table 11: Year of construction with mean benzene after removing outlier.

Building first constructed	Mean Benzene	N	Std. Deviation	Median	Maximum
2000 or later	4.80	95	4.92	3.09	22.24
1980 to 1999	4.68	344	5.68	2.91	35.56
1960 to 1979	4.93	46	6.52	2.16	31.29
1959 or earlier	2.63	22	4.48	1.18	16.63
Total	4.63	507	5.58	2.79	35.56

The month during which the data was collected was not significant to this project although we were trying to get all data collected before the weather encouraged householders to open their windows. The majority of the data was collected in March.

The "other" category was assigned to those for which the date was either incorrect or missing.

Figure 6. Indoor Air by month winter 2008



House Size

The indoor air benzene content was not related to the size of the house. Although there does seem to be a trend to higher benzene the larger the house, this is once again driven by a single value. Eliminating the outlier removed the trend.

Table 12: House size with mean benzene

House size	Mean benzene	N	Std. Deviation	Median	Maximum
> 3001 sq ft	5.38	95	7.91	2.88	58.29
2201 to 3000 sq ft	4.69	148	4.71	3.07	21.79
1501 to 2200 sq ft	4.78	205	6.48	2.43	34.55
<1500 sq ft	3.70	61	3.75	2.06	11.97
Total	4.74	509	6.06	2.88	58.29

ANOVA (p=.415)

The only factors that were clearly associated with increased indoor air benzene in this study were gasoline powered engines in the garage and gasoline storage in the house or garage. The number of vehicles kept in the garage was suggestive of an association but not statistically significant. Some vehicles are probably contributing more to exposure than others. In order to capture the effect of vehicles as well as other engines a new

variable was created that added vehicles plus engines. This variable was strongly associated with exposure to benzene in the house.

Table 13: Number of vehicles kept in garage

		Frequency	Percent
Valid	0	28	5.5
	1	204	40.1
	2	256	50.3
	3	17	3.3
	4	1	.2
Missing	Missing answer	3	.6
Total		509	100.0

Table 14: Number of gasoline-powered engines kept in garage

		Frequency	Percent
Valid	0	122	24.0
	1	158	31.0
	2	128	25.1
	3	48	9.4
	4	27	5.3
	5	8	1.6
	6	6	1.2
	7	7	1.4
	10	1	.2
Missing	Don't know	1	.2
	Missing answer	3	.6
Total		509	100.0

Since many households kept both gasoline powered engines and vehicles in the garage we added the two responses together to get an idea of the total exposure. You will note that while 122 households say they have no gasoline powered engines in the garage and 28 say they have no vehicles, only eight have neither engines nor vehicles in the garage.

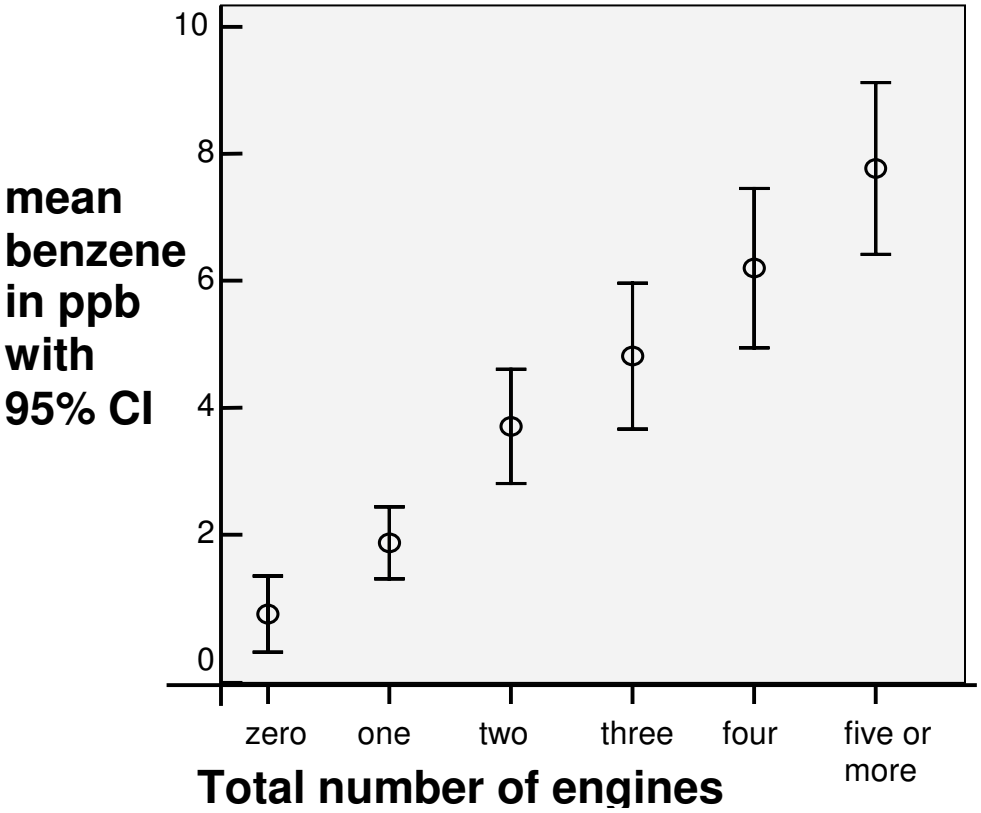
Table 15: Total number of vehicles and engines kept in the garage with mean benzene

Number of engines and vehicles	Mean benzene	N	Std. Deviation
zero	.57	8	.72
one	1.69	60	2.24
two	3.55	128	5.19
three	4.66	138	6.92
four	6.06	89	5.99
Five or more	7.81	80	6.20
Total	4.71	503	6.03

Df=4, p<.001, R squared= 0.094

There is strong association of benzene with the number of gasoline powered engines in the garage. Figure 7 shows this association. The linear nature of the graph indicates the strong effect on the indoor air quality of the residence of storing vehicles and gasoline engines in the garage.

Figure 7: Mean indoor air benzene in relation to gasoline engines in the garage.



The majority of households did store gasoline in the garage and this was associated with a higher mean benzene level. Gasoline appears to be the source of benzene in indoor air in Alaskan homes.

Table 16: Indoor air benzene * Gasoline brought or stored in house or garage

		Gasoline brought or stored in house or garage		
		Yes	No	Don't know
Benzene	more than median	194 (62%)	54 (28%)	1 (50%)
Total		312	190	2

Chi-square df=2, p<.001

Table 17: Gasoline brought or stored in house or garage with mean benzene

Gasoline stored in garage	Mean Benzene	N	Std. Deviation
Yes	5.74	312	6.40
No	3.06	190	5.14
Don't know	5.50	2	6.02
Total	4.73	504	6.09

ANOVA df=2, p<.001

Smoking

Other studies have indicated that smokers are a significant source of indoor air benzene. There were fewer smokers in this study than in the general public and only eight households or less than two percent allowed smoking in the house. There were two surveys that participants were asked to fill out. The household survey asked if there were smokers residing in the house. The following table is the response to that question.

Table 18: Smokers live in residence

Smoker in house	Frequency	Percent
Yes	46	9.0
No	463	91.0
Total	509	100.0

Those who answered yes to having a smoker in the house were asked where smoking was allowed.

These results indicate there is very little smoking indoors.

Table 19: Where people smoke

Where do people smoke	Frequency	Valid Percent
Outside only	21	46.7
Attached garage	15	33.3
Arctic entry	1	2.2
One room only	4	8.9
Anywhere in the house	4	8.9
Total	45	100.0
Missing answer	1	
No smokers	463	
total	509	

However, the health survey asked about the health of individuals and each individual was asked if he or she was a smoker. There were 55 positive responses.

Table 20: Does this person currently smoke?

Current smoker	Frequency	Percent
Yes	55	3.7
No	1424	95.1
Total	1479	98.8
Missing answer	5	.3
total	1497	100.0

There is a discrepancy in the number of smokers between the two survey instruments. This indicates there are fifty-five smokers but only 46 households indicated that there was a smoker in residence, perhaps the smokers live together. However a cross tabulation shows that at least 14 smokers are living in households that denied that there were smokers in the household. If we were to add an additional 14 households to the 46 who claim to have smokers we have a total of 60 households with smokers but only 55 people who admit to being smokers. Obviously there were households that said they had smokers but no one filling out the health form admitted to being a smoker. Therefore the smoking data from this survey has a high proportion of misclassifications and is not sufficiently reliable to determine whether smokers alone could raise the indoor air benzene to a level higher than the median. However, even if there are a total of 60 smokers in the households, it is still less than 12% of the households.

Table 21: Person currently smokes * Smokers live in residence

		Smokers live in residence		
		Yes	No	Total
Person currently smokes	Yes	41	14	55
	No	81	1329	1410
Total		122	1343	1465

Health Results

There were two surveys completed and returned from each household. One was a household survey which asked questions about the house. The other was a health survey which was to be completed by or for each resident of the house, parents answering for children. The difficulty of analyzing the health data was that the responses were no longer independent as there were anywhere from one to fifteen responses per household. To analyze this data we consulted with Alistair Stewart, a biostatistician from the University of Auckland, New Zealand.

Demographics

This was a self-selected population who responded to the invitation to measure benzene in their own homes. The participants in this study were predominantly white females. Eighty-five persons (5.7%) identified themselves as Asian or Pacific Islander. All other races were less than two percent except mixed race category of 57 persons (3.8%). The following table is a summary of the demographics of the population.

Table 22: Demographics of the participants

demographic	Yes	No	Missing
employed	826 (55.7%)	658 (44.3%)	0
female	761 (50.8%)	719 (48.0)	4 (0.2%)
Hispanic	53 (3.5%)	1288 (85.7%)	148 (9.9%)
Under 19 years old	458 (30.6%)	1023 (68.9%)	3(0.2%)
Between 20 and 65 years	1010 (67.5%)	474 (31.9%)	3(0.2%)
Over 65 years	13 (0.9%)	1471(99.1%)	3(0.2%)
Caucasian	1264 (84.4%)	212(14.3%)	8 (0.6%)

The majority of persons spent more than 8 hours in their home and a large number had lived in the home for many years. There was no association between length of time spent in the home or number of years of residence and benzene levels or illness factors.

Table 23: Hours per day spent inside house

Hours spent in the house	Frequency	Valid Percent
8 hours or less	54	3.7
9-12 hours	471	31.9
13-16 hours	706	47.8
More than 16 hours	246	16.7
Missing answer	7	
total	1484	

Figure 24: length of time person has resided in house

Years living there	Frequency	Percent
<3 years	168	11.3
3-6	504	33.9
7-10	322	21.7
>10 years	490	33.1
Total	1484	100.0

Determining Health Risk Levels of Benzene

The original intent of this research was to document the level of asthma in homes where residents may be exposed to very high environmental concentrations of benzene. It was proposed that because benzene affects the immune system people having daily exposure higher than average might be inclined to have greater prevalence of asthma and allergic diseases. Other health effects might also become apparent as the questionnaire asked questions regarding asthma symptoms and self-assessed health status.

To begin we had to decide on a level of exposure that might cause health effects. As all exposures were lower than occupational exposures, we looked to the Agency for Toxic Substances and Disease Registry (ATSDR) for guidance. The agency did provide minimal risk levels (MRL) for inhaled benzene that were within the range of our observations. An explanation of the MRL is taken from the ATDRS' website.

"An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure….ATSDR uses the no observed adverse effect level/uncertainty factor (NOAEL/UF) approach to derive MRLs for hazardous substances. They are set below levels that, based on current information, might cause adverse health effects in the people most sensitive to such substance induced effects. MRLs are derived for acute (1 - 14 days), intermediate (>14 - 364 days), and chronic (365 days and longer) exposure durations, and for the oral and inhalation routes of exposure."
We divided the exposure into three levels based on the minimal risk levels as found at the ATSDR website for benzene inhalation exposure. The MRL for inhaled benzene is 3 parts per billion (ppb) chronic exposure daily for one year or more. The intermediate risk level was exposure to greater than 3 but less than 9 parts per billion for from 14 to 364 days, and the acute risk according to ATSDR is exposure to more than 9 parts per billion for more than 14 days. Here is how it breaks down for our study.

Table 25. Benzene Levels by ATSDR Minimum Risk Levels

			Benzene Levels			
Risk Level	Individuals	Houses	Mean	Median	Minimum	Maximum
Minimal risk <3ppb	787	275	1.30	1.25	0.00	2.98
Intermediate risk 3-9 ppb	441	161	5.20	4.75	3.01	8.86
Acute risk 9 or + ppb	252	81	15.58	12.27	9.17	58.29

Asthma Outcomes

While we do not see an increased prevalence of asthma or allergies, we do see a significant increase in severity of asthma in homes with elevated benzene level and a non-significant increase in dry cough.

Table 26. Symptoms by Minimum Risk Levels

Percentage with Outcome in the Benzene Category	Benzene Levels		
	<3ppb	3-9ppb	>9ppb
Wheeze	12.8	13.7	14.2
Severe asthma	5.4	6.3	10.6
Asthma attacks	4.0	4.1	6.5
Sleep disturbance	0.8	1.2	0.8
Exercise-induced asthma	11.8	13.7	15.4
Dry Cough	14.1	14.2	17.9
Diagnosed Asthma	12.4	13.1	12.5
Allergies	30.8	31.0	30.8

Asthma diagnosis was a lifetime diagnosis and hence may not be related to the current residence. However, we also did not see an increase in asthma diagnosis in children who were likely to have spent a larger proportion of their lifetime in the residence. Severe asthma was computed by adding asthma symptoms.

The figure is a pictorial representation of the table above

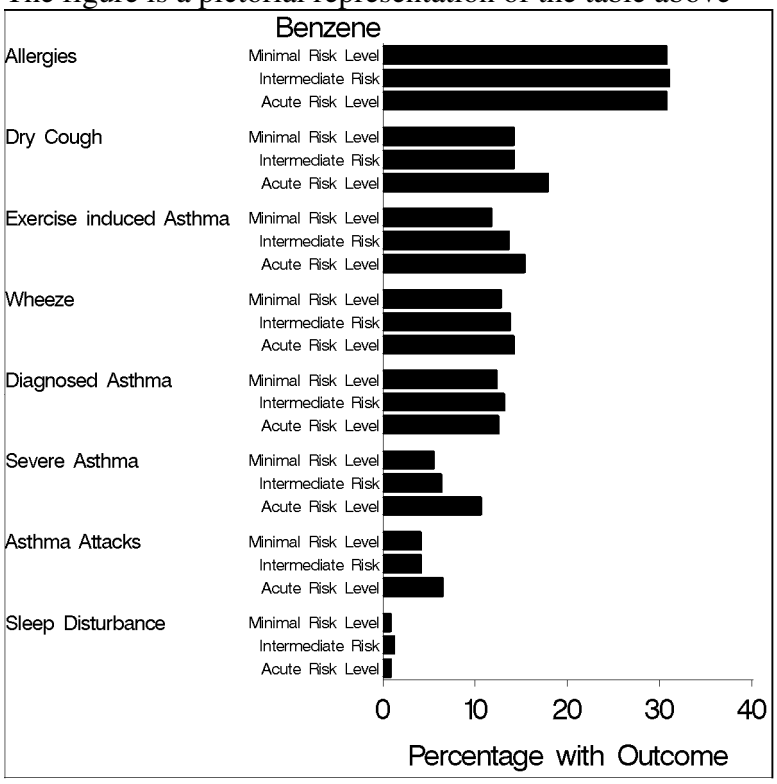


Figure 8: Symptoms by Benzene Risk Level

These eight outcome measures have been modeled to assess whether there is a difference in the proportion with the outcome for the different levels of indoor air benzene exposure. There may be some confounding by age, exposure to benzene at work or as a hobby, pets in the home, indoor molds or moisture and smokers in the home and so these factors have also been included in the model.

In none of the analyses did the regression coefficients change much when the confounders were added to the model (see Table below). This table shows the Odds Ratio of the Intermediate and Acute Risk groups for the different symptoms as compared to the group with less than 3 ppb of benzene in the indoor air.

The modelling for the analyses was done by using a generalised linear mixed model. This was a logistic model with the households being modelled as a random effect. The test of the benzene effect was the combined effect of the 2nd and 3rd levels of benzene compared with the lowest level. It is these two contrasts that are reported as Odds ratios.

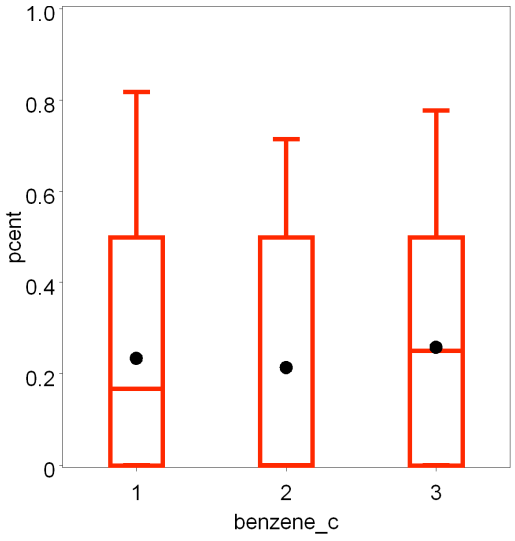
Table 27: Odds Ratios for Symptoms

Odds Ratio (95%CI)	Model Type	Benzene Risk	
		Intermediate	Acute
Wheeze	No confounders in model	0.98(0.60,1.60)	1.11(0.62,2.01)
	Confounders included	1.03(0.63,1.68)	1.15(0.63,2.09)
Severe asthma	No confounders in model	1.17(0.63,2.18)	2.10(1.07,4.13)
	Confounders included	1.34(0.70,2.54)	2.49(1.22,5.07)
Asthma attacks	No confounders in model	0.95(0.47,1.90)	1.60(0.74,3.43)
	Confounders included	1.06(0.52,2.17)	1.80(0.80,4.06)
Sleep Disturbance	No confounders in model	1.49(0.42,5.32)	1.05(0.19,5.72)
	Confounders included	1.23(0.32,4.64)	1.00(0.17,5.88)
Exercise-induced Asthma	No confounders in model	1.22(0.74,2.03)	1.42(0.78,2.61)
	Confounders included	1.28(0.76,2.13)	1.48(0.80,2.76)
Dry cough	No confounders in model	1.00(0.61,1.64)	1.34(0.74,2.42)
	Confounders included	1.06(0.64,1.74)	1.49(0.81,2.73)
Diagnosed asthma	No confounders in model	0.96(0.62,1.50)	0.90(0.52,1.56)
	Confounders included	1.04(0.67,1.63)	1.06(0.61,1.85)
Allergies	No confounders in model	1.07(0.74,1.53)	1.02(0.65,1.60)
	Confounders included	1.11(0.77,1.61)	1.13(0.72,1.79)
Odds Ratios Relative to Benzene at Minimal Risk Level			

Children

Children are an important sub-category as their exposure may be more intense because of the increase in time spent in the home and their more rapid respiratory rate.

The distribution of the proportion of children in the house where the houses are categorized by their benzene levels is shown in the boxplot. It can be seen that the proportion of children in a house is independent of the benzene levels.



The black dot is the mean level. The horizontal bar in the box is the median. For benzene level 2 the median is at zero and so the bar can not be seen.

No symptoms reach statistical significance when only children were considered. There were only 335 observations when only children were considered.

Figure 9 Children by Benzene Risk Level

Work and Hobby Exposure

Some confounders of residential exposure would be possible work exposure and hobby exposure. The individual health surveys included questions about work and hobby exposure to gasoline or benzene.

Table 28. Work Exposure and Minimum Risk Levels

Benzene Levels	Exposure in the Workplace					
Frequency	Daily	weekly	monthly	yearly	never	Total
Below MRL	53	54	38	77	565	787
Percent	6.7	6.9	4.8	9.8	71.8	100.0
Intermediate	37	26	30	34	314	441
Percent	8.4	5.9	6.8	7.7	71.2	100.0
Acute Risk	29	14	21	15	173	252
Percent	11.5	5.6	8.3	6.0	68.7	100.0
Total	119	94	89	126	1,052	1,480
Percent	8.0	6.4	6.0	8.5	71.1	100.0

There are 29 or 11.5% of the Acute Benzene Risk Level respondents that have daily exposure to gasoline or chemicals at work. There is a trend for those who have a higher exposure at work to live in homes with higher benzene levels (P=0.016 for daily v less frequent exposure at work).

Table 29. Hobby Exposure and Minimum Risk Levels

Benzene Levels	Exposure Related to Hobbies					
Frequency	Daily	weekly	monthly	yearly	never	Total
Below MRL	6	48	85	144	482	765
Percent	0.8	6.3	11.1	18.8	63.0	100.0
Intermediate	1	17	56	91	252	417
Percent	0.2	4.1	13.4	21.8	60.4	100.0
Acute Risk	3	17	39	45	133	237
Percent	1.3	7.2	16.5	19.0	56.1	100.0
Total	10	82	180	280	867	1,419
Percent	0.7	5.8	12.7	19.7	61.1	100.0

Only 1% of the acute risk level respondents have daily exposure to gasoline or chemicals in their hobbies. There is no trend for those who have a higher exposure in their hobbies to live in homes with higher benzene levels (P=0.98 for daily or once per week v less frequent exposure in hobbies).

General Health

Besides asthma, we also asked questions about the general health of the participants. The state of one's general health is a very subjective question as 30% of those who answered that they had excellent health answered yes to one or more of the symptom questions and 50% of those who stated they had less than excellent health answered no to all of the symptom questions. However, a subjective impression of one's health is a valid question for investigating the quality of indoor air.

Table 30. General Health Distribution

Benzene Levels	General Health				
	Excellent	Good	Fair	Poor	Total
Below MRL	477	278	26	5	786
Percent	60.7	35.4	3.3	0.6	
Intermediate	242	177	19	1	439
Percent	55.1	40.3	4.3	0.2	
Acute risk	123	113	14	1	251
Percent	49.0	45.0	5.6	0.4	
Total exposure	842	568	59	7	1,476
Percent	57.1	38.5	4.0	0.5	100.0

The numbers are too small to calculate accurately if we combine the general health condition of good/excellent and fair/poor. Thus general health was divided into two categories which gave us some discriminatory power. Either general health is excellent or general health is not excellent.

Table 31. General Health "Not Excellent"

Percentage with Outcome in the Benzene Category	Benzene Levels		
	<3ppb	3-9ppb	>9ppb
General Health (not excellent)	39.3	44.9	51.0

Table 32. General Health "Not Excellent" by Age

Percentage with Outcome in the Benzene Category	Benzene Levels		
	<3ppb	3-9ppb	>9ppb
Percentage with "Not Excellent" General Health at Ages:			
Less than 5 (n=41)	11%	14%	6%
5–12 (n=193)	17%	20%	37%
13–19 (n=178)	22%	26%	29%
Over 20 (n=1,018)	49%	55%	63%

For comparison if we were to add good and excellent health together as a category we would have no power to determine differences. The following table shows the proportion of fair and poor responses by age.

Table 33. General Health "Fair" or "Poor" by Age

Percentage with Outcome in the Benzene Category	Benzene Levels		
	<3ppb	3-9ppb	>9ppb
Percentage with "Not Excellent" or "Good" General Health at Ages:			
Less than 5 (n=41)	Only 1 subject not in excellent/good health		
5–12 (n=193)	No subjects not in excellent/good health		
13–19 (n=178)	Only 4 subjects not in excellent/good health		
Over 20 (n=1,018)	5.5%	5.6%	8.3%

Table 34 shows the differences between the two ways of determining categories.

Table 34. Comparison of Different Methods of Analyzing General Health

Percentage with Outcome in the Benzene Category	Benzene Levels		
	<3ppb	3-9ppb	>9ppb
General Health (not excellent)	39.3	44.9	51.0
General Health (fair or poor)	3.9	4.6	6.0

Table 35. Analysis of General Health by Two Distributions

Odds Ratio (95%CI)	Model Type	Benzene Risk	
		Intermediate	Acute
General Health*	No confounders in model	1.40(0.91,2.17)	1.69(0.99,2.90)
	Confounders included	1.61(0.97,2.67)	2.25(1.19,4.27)
*General health is excellent v. good/fair/poor			
General Health**	No confounders in model	1.11(0.55,2.25)	1.06(0.44,2.53)
	Confounders included	1.26(0.60,2.61)	1.40(0.57,3.44)
**General health is excellent/good v. fair/poor			

When all the potential confounders (age, work exposure, hobby exposure, pets moist, mold and smoking) are included in the model the association of (non excellent) general health possibly shows a stronger relationship with benzene exposure P=0.024). As general health is associated with age, the inclusion of age in the model appears to be an important confounder. Age cannot be shown to be an effect modifier (i.e. no interaction P=0.46).

Conclusions

The Indoor Air Study measured the indoor air benzene in over 500 residences with attached garages in Anchorage, Alaska. The level of indoor air benzene exceeded the ATSDR minimal risk levels in almost half of the homes tested. The increased benzene was related strongly to the number of gasoline powered engines including vehicles and small gasoline engines that were in the garage and whether gasoline was stored in the garage.

The ATSDR minimal risk levels were determined by extrapolation from studies in humans and animals of much higher exposures and are directed to prevent harm to the most vulnerable members of the population. There was no increase in the prevalence of asthma or allergies in residents living in the homes that exceeded the ATSDR acute level risk.

Although there was no increase in prevalence of asthma there was a significant increase in the severity of asthma among the residents exposed to more than 9 ppb of benzene in their homes. People with asthma are a more vulnerable population. This finding supports the ATSDR minimal risk designations for inhaled benzene, indicating that the level of benzene found in some homes in Anchorage is harmful to vulnerable persons.

There is also some suggestion that residents living in homes with levels of benzene that exceed the minimal risk level have a perceived decrease in their state of health. Personal monitoring of this high risk population might help reduce classification errors and inform this important outcome.

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1) Agency for Toxic Substances and Disease Registry, Public Health information regarding benzene (http://www.atsdr.cdc.gov/toxprofiles/phs3.html#bookmark05).

2) Goldstein B, Tardiff R, Baker S, Hoffnagle G, Murray D, Catizone P, Kester R, Caniparoli D. *Valdez Air Health Study*, June 15, 1992.

3) Schlapia A, Morris S. *Architectural, Behavioral and Environmental Factors Associated with VOCs in Anchorage Homes Document #98-A504*, June, 1998.

4) Lan Q, Zhang L, Li G, Vermeulen R, Weinberg RS, Dosemeci M, Rappaport SM, Shen M, Alter BP, Wu Y, Kopp W, Waidyanatha S, Rabkin C, Guo W, Chanock S, Hayes RB, Linet M, Kim S, Yin S, Rothman N, Smith MT. *Hematotoxicity in workers exposed to low levels of benzene.* Science 306(5702):1774-6 Dec 3 2004.

Appendices

1) Recruitment Letter
2) Household survey
3) Health survey

<merge current date>

Dear <merge first and surname>,

The University of Alaska Anchorage, working with the Municipality of Anchorage, invites you to participate in a research study of the health effects of indoor air pollutants in Anchorage.

If you complete the questions below and return this letter, we will send you a small box containing a health survey for each person in the house, one household survey, and a small vapor monitor to measure benzene in your home. We'll ask you to complete the brief, confidential health surveys (parents will respond for children) and the household survey. We will also ask you to open the monitor that measures benzene, display it in your home for one week, and return it to us together with the completed surveys (we'll pay the postage).

Within two months from the time you return the package, we'll send you a **check for $10** (1 per household) and **two tickets to the Bear Tooth Theatre.** We will also provide you with the results of the benzene measurement in your home. In addition, all participants will be **eligible to enter a drawing for $100 cash**. In March 2008, a total of eight winners will be drawn (only participants can win). Each winner will receive $100.

Here are the questions:

1. Is your mailing address correct? ➔ Yes

   If not, please write the correct address._____

2. Daytime phone number(s) _____ / _____

3. How long have you lived at this address? _____years and _____months

4. Is there an attached or tucked-in garage at this address? **Yes** **No**

5. Do you use the garage to park a car or to store gasoline or gasoline-powered engines, such as snow machines, lawn mowers, or generators? **Yes** **No**

6. How many people (**including you**) live in this house? ➔ _____

7. Are you willing to participate in a study to measure exposure to indoor air pollutants in your home and to answer questions about your health and the health of your family?	❑ Yes ❑ Maybe, but I have questions: please call me at the number above between _____ and _____ a.m. or p.m.

If you would like additional information, you may call me at 786-6569.

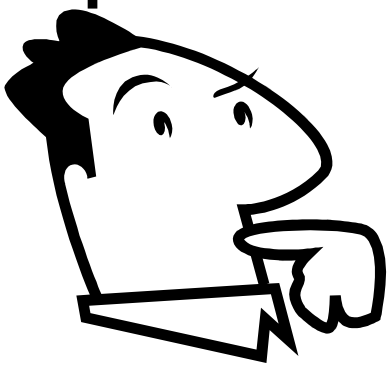
Mary Ellen Gordian, MD, MPH
Assoc. Professor of Environmental Health, University of Alaska Anchorage

Dr. Mary Ellen Gordian
Institute of Social and Economic Research
University of Alaska Anchorage
3211 Providence Dr.
Anchorage, AK 99508

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ fold here _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

The Municipality of Anchorage and the University of Alaska Anchorage want to know:

Are indoor air pollutants causing health problems?



_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ fold here _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

To return this form, refold it so the UAA address is showing, tape it closed, and drop it in the mail. No postage is required.

<merge name and address>

Household Questionnaire

On behalf of the Municipality of Anchorage and the Institute of Social and Economic Research at the University of Alaska Anchorage, we thank you for your participation and appreciate your taking a few minutes to complete this survey. Please write your answers or fill in the circles.

Address: _____ **Date:** _____ **Badge #** _____
(For Office Use)

HOUSING

H1. Which best describes this home?
- ❍ One-family house detached from any other house
- ❍ Building with 2-4 units
- ❍ Building with 5 or more units

H2. About when was this building first constructed?
- ❍ 2000 or later
- ❍ 1980 to 1999
- ❍ 1960 to 1979
- ❍ 1959 or earlier

H3. What is the approximate square footage of this home? _____ sq. ft.

H4. How many people reside permanently at this address?
Total # of people:_____
# of people under 18:_____

H5. On average, how many automobiles, vans, or trucks are kept in the attached garage in the winter? # of vehicles: _____

H6. On average, how many machines with gasoline engines (snow machines, snow blowers, lawn mowers, ATVs, generators, chain saws, etc.) are stored in the attached garage or arctic entry?
# of machines with gasoline engines: _____

H7. What is the primary heating system in this house?
- ❍ Forced air heat
- ❍ Radiant hot water heat
- ❍ Other _____

H8. What is the primary heating source?
- ❍ Natural gas
- ❍ Electricity
- ❍ Fuel oil, kerosene, or other liquid fuel
- ❍ Coal
- ❍ Wood
- ❍ Other, please specify _____

H8a. Do you use a secondary or supplemental source of heat?
❍ Yes ❍ No
↓
Please specify _____

H9. Where is the heating system furnace or boiler located in this house?
- ❍ Inside the garage
- ❍ Crawl space
- ❍ Basement
- ❍ Other room; please specify_____
- ❍ Outside the house

H10. How many animals with fur or feathers live **MOST** of the time inside this house?
total # of animals with fur or feathers: _____

AIR

H11. Other than opening the windows, is there a ventilation system built into this house?
❍ Yes ❍ No
↓
H11a. What kind?
_____

H12. Are there people living in this house who smoke cigarettes, cigars, or pipes?
❍ Yes ❍ No
↓
H12a. Where do people smoke?
- ❍ Outside only
- ❍ Attached garage
- ❍ Arctic entry
- ❍ One room only
- ❍ Anywhere in the house

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WATER AND MOISTURE

H13. **IN THE PAST 12 MONTHS**, has moisture ever condensed on the windows in this house?
❍ Yes ❍ No
↓
H13a. If yes, how often?
❍ Occasionally, on very cold days, minus 10° F. or colder
❍ Often, when the temperature is below 0° F.
❍ Frequently, even at temperatures above 0° F.

H14. **IN THE PAST 12 MONTHS,** have you ever seen mold or mildew growing on the walls, ceiling, or floors in the house, garage, or arctic entry?
❍ Yes ❍ No
↓
H14a. In what room(s) have you seen mold or mildew?_____

H14b. Currently, is there mold or mildew on any surface in the house, garage, or arctic entry?
❍ Yes ❍ No

H15. Do you **EVER** experience "moldy" odors in this house?
❍ Yes ❍ No

H16. Does anyone **BRING OR STORE** gasoline in this house or its attached garage or arctic entry to use, for example, in lawn mowers, snow machines, or other equipment?
❍ Yes ❍ No ❍ Don't Know
↓
H16a. If yes, how often?
❍ Once a week or more
❍ Less than once a week, but at least once a month
❍ Less than once a month, but at least once a year

H17. Does anyone regularly use glue, solvents, paints, or other chemicals in this house, attached garage, or arctic entry for projects or hobbies?
❍ Yes ❍ No ❍ Don't Know
↓
H17a. If yes, how often?
❍ Once a week or more
❍ Less than once a week, but at least once a month
❍ Less than once a month, but at least once a year

HOUSEHOLD INCOME IN THE PAST 12 MONTHS

H18. During the past 12 months, what was the total income of this household?

❍ Less than $20 thousand
❍ $20 – $39 thousand
❍ $40 – $59 thousand
❍ $60 – $99 thousand
❍ $100 thousand or more

DO YOU HAVE ANY COMMENTS TO SHARE WITH US?

THANK YOU FOR COMPLETING THIS SURVEY

Health Questionnaire

On behalf of the Municipality of Anchorage and the Institute of Social and Economic Research at the University of Alaska Anchorage, we thank you for your participation and appreciate your taking a few minutes to complete this survey. Please write your answers or fill in the circles.

Address: _____ Date: _____ Badge # _____

I have read the Informed Consent and agree to participate in this study.

Print Name _____

Sign Name _____

I am filling out this survey for

❍ me ❍ my spouse ❍ my child

❍ other _____ (please specify relationship between you and this person)

ALL SUBSEQUENT QUESTIONS REFER TO THE PERSON ON WHOSE BEHALF THIS FORM IS BEING ANSWERED.

RESIDENCE

A1. How long has this person lived in this house? _____(yrs) _____ (mos)

A2. On average how many hours per day does this person spend in this house?

❍ 8 hours or less
❍ 9-12 hours
❍ 13-16 hours
❍ More than 16 hours

EMPLOYMENT AND OCCUPATION

B1. This person is currently (mark all that apply)

❍ A child ❍ A student
❍ Unemployed ❍ Homemaker
❍ Retired ❍ Employed
❍ Active Duty in U.S. Armed Forces
❍ Other (please specify)
_____

B2. In the last 12 months, did this person work for pay at a job (or business)?

❍ Yes ❍ No ➔If no, **skip to Q. B4** ➔ ↓

Continue with Q.B2a

B2a. What type of business or industry? _____

B2b. What is this person's job or occupation? _____

B3. At this job, does this person come into contact with or work around gasoline, solvents, or chemicals?

❍ Daily
❍ Not daily, but at least once a week
❍ Not weekly, but at least once a month
❍ Not monthly, but at least once a year
❍ Never

B4. Does this person have hobbies that require handling gasoline (as fuels or solvents), other solvents, or chemicals?

❍ Daily
❍ Not daily, but at least once a week
❍ Not weekly, but at least once a month
❍ Not monthly, but at least once a year
❍ Never

SMOKING

C1. Does this person currently smoke cigarettes or cigars? ❍ Yes ❍ No➔If no, skip to Q. C2

C1a. If this person smokes cigarettes, how much does he/she smoke?

❍ Fewer than 5 cigarettes per day
❍ 5–20 cigarettes (less than a pack/day)
❍ More than a pack per day

C1b. If this person smokes cigars, how much does he/she smoke?

❍ Fewer than 2 cigars per week
❍ Between 2 and 6 cigars per week
❍ One cigar or more per day

C2. Has this person **EVER** been a smoker?

❍ No ❍ Yes ➔ C2a. When did this person last smoke? (_____(month)./ _____(year)

CONTINUE ON THE BACK OF THE PAGE

HEALTH

D1. What is the general health of this person?
- ❍ Excellent
- ❍ Good
- ❍ Fair
- ❍ Poor

D2. Does this person have any long-term illness?
- ❍ Yes
- ❍ No
- ❍ Don't Know

↓

D2a. What illness(es) does he/she have?

_____

D3. Has this person **EVER** had wheezing or whistling in his/her chest at any time?
- ❍ Yes
- ❍ No

D3a. If yes, in the last 12 months?
- ❍ Yes
- ❍ No

↓

D3b. How many attacks of wheezing in the last 12 months? _____

In the last 12 months . . .

D4a. How many times has this person awakened from sleep with wheezing?
- ❍ Never
- ❍ Less than once a week
- ❍ More than once a week

D4b. Has wheezing ever been severe enough to limit his/her speech to 1 or 2 words between breaths?
- ❍ Yes
- ❍ No

D4c. Has his/her chest ever sounded wheezy during or after exercise?
- ❍ Yes
- ❍ No

[In the last 12 months continued . . .]

D4d. Has this person used medications such as inhalers or pills to help breathing?
- ❍ Yes
- ❍ No

D4e. Has this person had a dry cough at night without a cold or chest infection?
- ❍ Yes
- ❍ No

D4f. How many respiratory infections (colds, earaches, bronchitis, etc.) has this person had?
- ❍ 0 - 1
- ❍ 2 - 3
- ❍ 4 - 5
- ❍ More than 5

D5. Has this person EVER been diagnosed with asthma?
- ❍ Yes
- ❍ No
- ❍ Don't Know

↓

D5a. How long has this person had asthma?

_____

D6. Does **this person** have allergies to foods, pollens, dust, etc?
- ❍ Yes
- ❍ No

D7. Does this person have a **family history** of asthma (ie, blood relatives with asthma)?
- ❍ Yes
- ❍ No

D8. Does this person have a **family history** of allergies to foods, pollens, dust, etc. (ie, blood relatives with allergies)?
- ❍ Yes
- ❍ No

E1. What is the gender of this person?
- ❍ Male
- ❍ Female

E2. What age is this person?
- ❍ Less than 5 years
- ❍ 5 – 12
- ❍ 13 – 19
- ❍ 20 – 65
- ❍ Over 65

E3. What is this person's race? (mark one or more boxes)
- ❍ White (Caucasian)
- ❍ Black, African American, or Negro
- ❍ American Indian or Alaska Native
- ❍ Asian/Pacific Islander
- ❍ Some other race

E4. Is this person of Hispanic ethnicity?
- ❍ Yes
- ❍ No

DO YOU HAVE ANY COMMENTS TO SHARE WITH US?

THANK YOU FOR COMPLETING THIS SURVEY